

Docket No. 18733/00040
Serial No. 09/803,560

SUBSTITUTE SPECIFICATION

METHOD FOR MANUFACTURING A HOLLOW RACK SHAFT

[0001] This application is a divisional of co-pending U.S. Patent Application Serial No. 09/803,560, filed March 9, 2001, which is based on Patent Applications No. 2000-64298, No. 2000-114306 and No. 2000-114502 filed in Japan, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] This invention relates to a hollow rack shaft, and more particularly to a method for manufacturing a hollow rack shaft for a steering system used in an automobile.

2. Description of the Related Art

[0003] In the case of a rack-and-pinion type steering system for an automobile frequently used in the automotive industry, the rotation of a steering wheel operated by a driver is transmitted to a pinion. The rotation of this pinion is transmitted to a rack shaft engaged with the pinion and this is converted into a motion in a lateral direction (a longitudinal direction of the rack). Since the rack shaft is connected to a steering rod, the direction of the front wheels is changed by the lateral motion of the rack shaft. Since such a steering mechanism as described above is well known in the art, further description will be excluded.

[0004] The aforesaid rack shaft has been attained by gear cutting on a solid, namely not hollow, material. In recent years, as already described in Japanese Laid-Open Patent No. Hei 6-246379, Japanese Laid-Open Patent No. Sho 58-218339 (Japanese Patent Publication No. Hei 4-028582) and Japanese Laid-Open Patent No. Hei 11-180318, fuel efficiency of an automobile has been improved by making a hollow rack shaft to attain a more light weight rack shaft.

[0005] A manufacturing method for a forming rack is disclosed in Japanese Laid-Open Patent No. Hei 6-246379, which describes that a tube material is inserted into a first forming split die and a primary forming is carried out. Then, the aforesaid primary formed material is inserted into a secondary forming split die having, at a part of its inner surface, teeth corresponding to rack teeth, and a semi-circular mandrel is press fitted at one end of it.

[0006] A manufacturing method disclosed in Japanese Laid-Open Patent No. Sho 58-218339 describes that a die having teeth corresponding to rack teeth is pushed onto a tube material to form rack teeth wherein a mandrel is inserted into the tube material and the tube material is surrounded with a fixed die.

[0007] The manufacturing method disclosed in Japanese Laid-Open Patent No. Hei 11-180318 is an invention invented by Mr. Ohkubo, one of the inventors of the present invention. The manufacturing method comprises the following first to third steps. In the first step, a plate-like material originally having a substantial rectangular shape is bent into a gutter shape along a center of longitudinal direction. At this time, the central part of the gutter-shaped member is formed into a flat bottom section, and both the side portions are formed into a semi-circular shape having legs therein. In the second step, the rack teeth are plastically formed at the flat bottom portion. In the third step, the gutter-shaped material is bent such that the legs of the central part and the both sides are abutted to each other, and then a hollow rack shaft is formed.

[0008] In the cases disclosed in the first two gazettes above, a hollow workpiece is used as the original material, while, in the case disclosed in the third gazette (the gazette of Japanese Laid-Open Patent No. Hei 11-180318), a flat plate workpiece is used in place of the hollow workpiece, so that the third manufacturing method has some merits in view of material cost, transportation cost and storing cost. Further, according to the third manufacturing method, it is possible to avoid giving each portion except a tooth bottom portion an excessive thickness in order to maintain the tooth bottom portion at a required wall thickness. Thus, the rack shaft can be sufficiently light in weight.

SUMMARY OF THE INVENTION

[0009] However, it has become apparent that the manufacturing method disclosed in the gazette of Japanese Laid-Open Patent No. Hei 11-180318 has some problems not considered until now as described below.

[0009a] Although, in general, the deformation applied to the workpiece by a plastic working operation gives an almost permanent deformation, a temporary deformation, i.e. elastic deformation, remains in a part of the deformation. As the lead applied by the die is removed, the elastic deformation remaining at each minute element in the workpiece is restored and it is transferred to a new balanced state where each of the forces of the other fine elements keeps its balance. Due to this fact, after the workpiece is removed from the die, the entire workpiece does not take a shape coinciding with the die and its shape deviates from that of the die. In particular, in a case where a degree of forming is widely different among each of the locations on the workpiece, there is a large amount of deviation.

[0010] Figs.1a to 1c show a state where a flat plate workpiece is formed into a gutter-like shape in the first step of a prior art manufacturing method (the final stage of a press stroke). In this case, Fig.1a is a front sectional view for showing a workpiece and a die. Fig.1b is a sectional view taken along line B-B of Fig.1a. Fig.1c is a sectional view taken along line C-C of Fig.1a. The die set at the first step comprises an upper die set 110 including a right upper die 111, a left upper die 112 and a central upper die 113; and a lower die set 120 including a right lower die 121, a left lower die 122 and a central lower die 123. As is apparent from these figures, a workpiece W is formed by the lower die set 120 and the upper die set 110 into a gutter-like shape having a flat bottomed central portion 2a, where a rack tooth has not yet been formed, and having semi-circular bottomed portions 1 extending from the both sides of the flat bottomed central portion 2a.

[0011] Upon completion of the first step, when the upper die set 110 is lifted up to take out the workpiece W, the workpiece W takes a different shape from that of the lower die set 120 and the upper die set 110. Fig.2 is an exaggerated sectional view for showing the

workpiece W upon release of stress as described above. As shown in this figure, the workpiece W is warped like a bow with the bottom part of the gutter being placed inside, i.e. the opening of the legs being placed outside.

[0012] The reason why such a state occurs is as follows. The original plate workpiece is formed into a different shape at each portion. Therefore, the degree of deformation given to each portion differs from others. Namely, the degree of deformation given to the flat bottom portion 2a, the semicircular bottom portion 1 and the interface portion 9 of the workpiece are different from each other. When the load applied to the workpiece is unloaded after plastic working, each portion recovers elastically in a correspondingly different manner. Hence the workpiece warps like a bow.

[0013] Further, a similar problem may also occur in the second step of the prior art manufacturing method. Fig.3 is a sectional view for showing the workpiece W and the dies when rack teeth 2b are formed at the portion 2a (Fig.2) during the second step. The die set at the second step comprises an upper die set 210 including a right upper die 211, a left upper die 212 and a central upper die 213; and a lower die set 220 including a right lower die 221, a left lower die 222 and a central lower die 223. The upper surface of the central lower die 223 is formed with teeth complementary in shape to the rack teeth to be formed. In addition, the lower surface of the central upper die 213 is provided with a corrugated shape corresponding to the rack teeth.

[0014] The flat bottomed central portion 2a of the workpiece W is formed into a rack portion 2b having rack teeth by moving the central lower die 223 and the central upper die 213 towards each other while the semi-circular parts 1 of the workpiece W are respectively held between the right upper die 211 and the right lower die 221 and between the left upper die 212 and the left lower die 222.

[0015] Since many teeth are formed at the rack portion 2b, the degree of forming at each location is different. When the workpiece W is removed from the die upon completion of the second step, the workpiece W sometimes shows unintended deformation for the same reason as described above. Fig.4 illustrates one example of the workpiece W in which

deformation appears. In this case, the workpiece W is warped like a bow shape with the bottom part of the gutter being set inside, i.e. with the opening part of the leg being set outside.

[0016] Even if the third step for butting legs is applied to the workpiece W, which has unintended deformation after the second step, this deformation remains. Thus, as shown in Fig.5 in exaggerated form, the workpiece W having an unintended deformation (e.g., a bow-shaped warp) is attained. This deformed workpiece cannot be used as a rack shaft as it is.

[0017] In the second step of the prior art manufacturing method, another problem differing from the aforesaid problem may occur. Figs.6a and 6b show, respectively, a front sectional view and a sectional view taken along line B-B to illustrate this problem. It should be noted that these figures are illustrated in inverse relation in a vertical orientation against the aforesaid figures. In addition, side clamping dies 203 are auxiliary dies for clamping the workpiece W from side surfaces to prevent the workpiece W from being moved.

[0018] As already described above, rack teeth are formed by the central upper die 213 and the central lower die 223. These dies are designed such that the volume of the clearance composed of two dies is slightly larger than the volume of the workpiece W placed in the clearance when the central upper die 213 and the central lower die 223 are closest during the forming of the rack teeth.

[0019] However, in a case where the workpiece W is thicker than the intended thickness or in case where a volume of the aforesaid minimum clearance is smaller than the intended volume due to an error in the stroke of a press machine, the pressure at this clearance becomes quite high. Due to this fact, quite a high load is applied to the central upper die 213 and the central lower die 223 and, in particular, the load is concentrated at either the cavity 5a or the cavity 5b. The excessive load or fatigue of die material caused by repeated application of the load may generate a crack 5 (or damage) in dies 213, 223 as shown in Fig.6a.

[0020] In addition, when the rack teeth are formed, quite a large amount of material must flow, particularly near the teeth ends of the workpiece W, so a crack 5 may easily be generated at either the cavity 5a or the cavity 5b.

[0021] Further, in the third step of the prior art manufacturing method, another problem differing from the aforesaid problem is generated. Figs.7a to 7c, Figs.8a to 8c and Figs.9a to 9c are views for illustrating processes in which the hollow rack shaft is formed by bending both legs of the workpiece W so as to be butted to each other. Fig.7a, Fig.8a and Fig.9a are front sectional views. Fig.7b, Fig.8b and Fig.9b are sectional views taken along line B-B in the front sectional views. Fig.7c, Fig.8c and Fig.9c are sectional views taken along line C-C in each of the front sectional views, respectively.

[0022] At first, as shown in Figs.7a to 7c, the workpiece W having the rack teeth formed at the second step is supported on the lower die set 320 including the left lower die 322, the central lower die 323 and the right lower die 321. In addition, a pair of side lower dies 324 are arranged at the both sides of the central lower die 323 for supporting the lower side portion of the workpiece W. The upper surfaces of these dies have a shape that conforms well with the workpiece W having passed through the second step. In addition, the upper die 310 has, at its lower part, a semi-circular concave surface having a diameter that is approximately the same as a clearance at the legs of the workpiece W.

[0023] Then, when the upper die 310 descends, both legs 6 of the workpiece W are guided by the semi-circular concave surface and start to deform under application of a bending force directed inwardly. At this time, although a high bending moment is applied near the roots of the legs 6, only a low bending moment is applied to the location near the extremities of the legs 6. Due to this fact, as shown in Figs.8b and 8c, deformation progresses only at the location near the roots of the legs 6, while the portions near the extremities of the legs 6 are scarcely deformed.

[0024] Due to this fact, as shown in Figs.9a to 9c, even if the upper die 310 descends down to the end of the stroke, a linear portion 7 remains undeformed into an arc shape near the extremities of the legs 6. As a result, since the sectional shape is not a true circle,

the finished rack shaft becomes an inferior product. Further, since the butted end surfaces are not properly faced to each other, the end surfaces are inclined to form a V-shaped groove, so that they may become a hindrance when a welding operation, such as a laser welding operation and the like, is performed.

[0025] A cylindrical shape that is formed without strain by smoothly connecting the semi-circular bottom portion formed at the first step and the back arc portion formed at the third step is required, so a rack shaft formed as described above is repaired by a cutting or a grinding operation, or it is wasted as an improper product.

[0026] If it is assumed that a rack shaft having a deformed cylindrical part and a deformed semi-circular portion is attained, the grinding margin at the subsequent grinding step must be large in order to correct this deformed sectional shape into a right circular shape. This process may become a problem that not only increases manufacturing cost but also decreases the strength of the rack shaft as the grinding margin increases. As a result, the rack shaft is damaged or its lifetime is shortened. If the thickness of the original plate member is made thicker in compliance with the grinding margin to prevent a reduction in strength, another portion of the completed hollow rack shaft becomes thicker than required. This may become a problem in that the product may not satisfy the required weight reduction.

[0027] This invention aims at resolving these problems. In this invention, a hollow rack shaft is manufactured through a first step, a second step, and a third step, respectively. In the first step, a substantially rectangular plate workpiece is formed into a gutter-like shaped workpiece by press-forming. The gutter-like shaped workpiece has a bottom portion and a pair of leg-like side walls extending from side edges of the bottom portion substantially in parallel with each other. The bottom portion comprises a substantial flat bottom portion at a central portion in a longitudinal direction and semi-circular bottom portions at both outer sides. In the second step, a row of rack teeth is press-formed at the aforesaid flat bottom portion of the workpiece. In the third step, each of the pair of leg-like

sidewalls of the workpiece formed at the second step is bent into a semi-circular shape to be butted to each other.

[0028] In the first step of this invention, a first die set is used, wherein the first die set is provided with a surface having a complementary shape to each of the two semi-circular bottom portions in the gutter-like shape, and the surface is inclined in order to eliminate the elastic deformation generated in the workpiece when the workpiece is removed from the first die set.

[0029] In the second step of this invention, a second die set is used, wherein the second die set is provided with a die surface having a complementary shape to a row of rack teeth formed at the flat bottom portion, the surface also having a shape for canceling the elastic deformation of the workpiece when the workpiece is removed from the second die set.

[0030] In an alternate second step of this invention, a second die set is used, being provided with a die surface having a complementary shape to a row of rack teeth formed in the flat bottom portion, a part of the die surface being provided with recesses for releasing the surplus material of the workpiece in the die clearance at the end of the stroke of the press-forming. The second die set can be divided at the recesses into a plurality of segments. Each recess is located at a position where a protrusion formed by the recess does not interfere with a pinion engaged with the rack.

[0031] The alternate second step of this invention comprises a preliminary forming step and a main forming step, wherein in the preliminary forming step, a row of teeth, having substantially the same pitch as the pitch of a row of rack teeth finally formed and having a smaller pressure angle than a pressure angle of the rack teeth finally formed, is formed. And at the main forming step, a row of teeth formed at the preliminary forming step is reformed into a row of rack teeth having the required shape for the rack teeth. Further, in the main forming step, a part of the die surface is provided with a recess for releasing surplus material of the workpiece in the die gap, and it is possible to use the die set composed of a plurality of segments divided at the location of the aforesaid recess.

[0032] A third step in this invention is executed such that a mandrel, having at a part thereof a cylindrical outer surface corresponding to a hollow inner surface of the rack shaft, is inserted between the aforesaid pair of leg-like sidewalls. Further, this mandrel comprises at least two separable segments in such a way that it can be pulled out of the hollow rack shaft upon completion of the third step.

[0033] Other objects and advantages besides those discussed above shall be apparent to those skilled in the art from the description of a preferred embodiment of the invention which follows. In the description, reference is made to accompanying drawings, which form a part thereof, and which illustrates an example of the invention. Such example, however, is not exhaustive of various embodiments of the invention, and therefore reference made to the claims which follow by the description for determining the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention.

[0035] Figs. 1a to 1c show a state where a flat plate workpiece is formed into a gutter-like shape at the first step of the prior art manufacturing method.

Fig. 1a is a front sectional view for showing a workpiece and a die.

Fig. 1b is a sectional view taken along line B-B of Fig. 1a.

Fig. 1c is a sectional view taken along line C-C of Fig. 1a.

Fig. 2 is a sectional view for showing the state of the workpiece upon releasing of a stress such as is found in the prior art.

Fig. 3 is a sectional view for showing a workpiece and dies when the rack teeth are formed at the portion 2a in a second step of the prior art.

Fig. 4 is a sectional view for showing one example of the workpiece wherein deformation appears upon completion of the first step in the prior art.

Fig.5 is a sectional view for showing an example of the workpiece wherein the deformation shown in Fig.4 remains even after the third step in the prior art.

Figs.6a and 6b show a front sectional view and a sectional view taken along line B-B for illustrating an example in the prior art wherein a crack is generated at the die.

Figs.7a to 7c, Figs.8a to 8c and Figs.9a to 9c are views for illustrating processes where the hollow rack shaft is formed by bending both legs of the workpiece W so as to be butted to each other.

Fig.7a, Fig.8a and Fig.9a are front sectional views. Fig.7b, Fig.8b and Fig.9b are sectional views taken along line B-B in each of the figures. Fig.7c, Fig.8c and Fig.9c are sectional views taken along line C-C in each of the front sectional views.

Fig.10 is a front elevation sectional view for showing a state at the time when a flat plate workpiece is formed into a gutter-like shape in the first step of the method of this invention.

Fig.11 is a front elevation sectional view for showing a workpiece upon completion of the first step in which a bow-like warp of the workpiece is prevented by applying an inclination angle α to the die according to this invention.

Fig.12 is a front elevation sectional view for showing a state where a rack tooth formed in the second step of this invention is finished.

Fig.13 is a front elevation sectional view for showing the workpiece having no warp as attained in the second step of this invention.

Fig.14 is a front elevation sectional view for showing the die set used in the second step of this invention and the workpiece W formed by this die set.

Fig.15 is an enlarged sectional view for showing the workpiece in which protrusions f1 and f2 corresponding to a recess e were formed.

Figs.16 to 18 are front elevation sectional views for showing the die set and the workpiece according to this invention in order to illustrate a state in which a second step is divided into a preliminary forming step and a main forming step.

Fig.19 is a front elevation sectional view for showing an example according to this invention where the central lower die for the major forming step of the second step is divided.

Figs.20a to 22c illustrate the third step of this invention using a mandrel.

Figs.20a, 21a and 22a are front elevation sectional views.

Figs.20b, 21b and 22b are sectional views taken along line B-B of each of the figures.

Figs.20c, 21c and 22c are sectional views taken along line C-C of each of the figures.

Fig.23 is a view of an outer appearance of the completed hollow rack shaft according to this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0036] Now, preferred embodiments of the present invention will be described in detail while referring to the accompanying drawings.

[0037] In the preferred embodiments shown in the following description, the hollow rack shaft is manufactured through a first step, a second step and a third step. That is, an original plate-like workpiece of substantial rectangular shape is bent into a gutter-like shape along a center of a longitudinal direction. At this time, the central portion of the workpiece is formed into a flat bottom and both of its sides are formed into a semi-circular shape having legs. In the second step, rack teeth are formed in the flat bottom of the central portion by plastic machining. In the third step, the leg-like side walls are bent such that the edges of the walls are butted to each other, and thus a hollow rack shaft is formed. In this way, this invention is not different from the prior art manufacturing method in view of the fact that the method for manufacturing the hollow rack shaft in these preferred embodiments comprises three steps, although this invention is substantially different from the prior art manufacturing method in regard to the content of each of the steps. Due to this fact, in order to avoid overlapped descriptions about the content already described, only the differing points will be described.

First Embodiment

[0038] Fig.10 is a longitudinal sectional view for showing a flat plate workpiece having been formed into a gutter-like shape (a final end of a press stroke) during the first step of

the method of this invention. In the same manner as that of the prior art, upon completion of the first step, the plate workpiece W has a flat bottom at its central portion, and the workpiece is formed into a gutter-like shape including an unformed flat portion 602a in which to form rack teeth during the second step and a semi-circular portion 601 having a semi-circular bottom part. The die set used for this operation is also similar to that of the prior art. Namely, the die set comprises an upper die set 610 including a right upper die 611, a left upper die 612 and a central upper die 613; and a lower die set 620 including a right lower die 621, a left lower die 622 and a central lower die 623.

[0039] However, this invention is different from the prior art in view of the fact that the die surfaces of the right upper die 611, the left upper die 612, the right lower die 621 and the left lower die 622 corresponding to the bottom of the semi-circular portion 601 are inclined by a proper inclination angle α . Applying the proper inclination angle α to these dies, the bow-like warp of the workpiece W and the inclination angle α , as shown in Fig.2, are canceled by each other, and the bottom portions of the two semi-circular portions 601 are arranged along one line as shown in Fig.11 when the workpiece W is taken out of the die set. A value of the inclination angle α is adjusted according to the workpiece material and the sizes (length, width and thickness) of the workpiece W, respectively, so that the most appropriate value is selected on the basis of trial-and-error.

[0040] A bow-like warp in the workpiece W generated in the prior second step can also be canceled out by the same method as above. Fig.12 is a view for showing a case where the rack teeth are formed in the second step into the gutter-like workpiece W formed during the first step (or the gutter-like workpiece W formed during the first step of the prior art), and it illustrates when the step has been completed. The die set used in the second step comprises an upper die set 710 including a right upper die 711, a left upper die 712 and a central upper die 713; and a lower die set 720 including a right lower die 721, a left lower die 722 and a central lower die 723.

[0041] Rack teeth and corrugation are formed in the flat portion 602a by the central upper die 713 and the central lower die 723. As already described, in order to cancel a

bow-like warp of the workpiece W generated at this time, an inclination angle β is applied to each of the die surfaces corresponding to the bottom portion of each of the semi-circular portions 601, i.e. the right upper die 711, left upper die 712, right lower die 721 and left lower die 722, respectively. The appropriate inclination angle β is attained on the basis of a trial-and-error by similar way to the first embodiment.

[0042] As shown in the first embodiment, in the first step or the second step, the bow-like warp generated by the elastic recovering of the workpiece W when the workpiece W is removed from the die set can be substantially canceled out, as shown in Fig. 13, by applying either the inclination angle α or β to the die set. Due to this fact, any particular working step for correcting the bow-like warp is eliminated and the hollow rack shaft can be manufactured at a low cost.

Second Embodiment

[0043] In a second step of a second preferred embodiment, the die surface is provided with a recess for relieving an excessive increase in pressure in the die clearance at the end of the stroke of the pressworking. Fig. 14 is a longitudinal section for showing a die set 803 including a central upper die 813 and a central lower die 823 used in the second step, and the workpiece W formed by this die set. It should be noted that Fig. 14 to Fig. 19 are different from Fig. 1 in view of the fact that the upper or lower side of the workpiece W is reversed.

[0044] Each of the central upper die 813 and the central lower die 823 is a split type die composed of a plurality of segments 813S, 823S. Symbols 813D, 823D denote their dividing lines. The extremity of each of the segments 823S has a shape corresponding to one surface of the rack teeth and forms one rack tooth with the same shape of another adjoining segment 823S. Similarly, the extremity of each segment 813S is provided with a shape corresponding to the inside of the rack teeth and forms a shape similar to one tooth shape with the same shape of another adjoining segment 813S. Each of the central upper die 813 and the central lower die 823 is provided with a recess e, wherein this recess e is arranged to pass through the dividing lines 813D, 823D. Accordingly, each recess e is

positioned at the rack tooth or at the tooth bottom part of a shape similar to the tooth shape.

[0045] When the rack teeth are formed by the central upper die 813 and the central lower die 823 having recesses *e* as described above, if the material of the workpiece *W* within the die clearance at the end of stroke of the pressworking is excessive, the material flows into the recess *e*. As a result, it is possible to prevent the pressure within the die clearance from being excessively increased. Thus, it is possible to prevent the die from being damaged or cracked. Also, at this time, protrusions *f1*, *f2* indicated in Fig. 15 are formed at locations corresponding to the recesses *e* of the workpiece.

[0046] Since the protrusion *f2* is formed on the rack teeth at a location opposite the tooth bottom of a pinion when the rack teeth are engaged with the pinion *p*, a sufficiently large clearance *d* is established, in view of design such that there is no possibility that the protrusion *f2* will become a hindrance when coming into contact with the pinion *p* in gear transmission. Since the protrusion *f1* is placed at an opposite side of the rack teeth, it does not become a hindrance in gear transmission.

[0047] The second step is divided into two steps, i.e. a preliminary forming step and a main forming step to prevent the die from being damaged. Figs. 16 and 18 are longitudinal sections for showing the die set and the workpiece *W* when the preliminary forming step and main forming step have been completed. In addition, Fig. 17 is a longitudinal section between the die set and the workpiece *W* indicating the initial state of the main forming step.

[0048] The preliminary forming process is carried out by the die set 903 including the central lower die 923 and the central upper die 913. In the preliminary forming step, an intermediate shape to reach to the final shape is formed. The teeth formed by the central lower die 923 in the preliminary forming process are not narrowed at the upper end as is the final rack tooth shape. Describing in more detail, the tooth thickness *A* at the tooth end is slightly thinner than the tooth thickness *B* at the tooth root. The best shape is that the tooth is tapered such that the tooth end thickness *A* is thinner than the root *B* in order

to remove the workpiece W easily from the central lower die 923 after the preliminary step has been completed. The pressure angle is smaller than the final tooth shape.

[0049] The tooth thickness A and the tooth thickness B are designed thinner than a tooth size of rack teeth of the product. It is desirable that the plate thickness t at the tooth root portion is established as same as that of the tooth root of the product. The phase and pitch are established as same as those of the rack teeth of the product. The tooth shape formed in the preliminary forming step is optional except their pitch and phase.

[0050] This preliminary forming process is a simple forming process, so that the material easily flows, and a load to the die set 903 can be remarkably reduced as compared with that of forming the rack teeth in one step.

[0051] As shown in Figs.17 and 18, in the main forming process, a die set 1003 for the main forming process is composed of a central lower die 1023 having a complementary shape to the shape of the product rack. Since the workpiece is already formed to a shape approximating the final product by the preliminary forming step, the requisite material flow is less in its volume, so the load applied to the die can be substantially reduced.

[0052] The dies 913, 923, 1013 and 1023 shown in Figs.16 to 18 can be divided into segments. Fig.19 shows an example in which the die set 1003 for the main forming process is composed of the central lower die 1023 and the central upper die 1013; each of dies 1023 and 1013 comprises a plurality of segments 1023S and a plurality of segments 1013S, respectively.

[0053] In the second embodiment, a die load can be reduced by flowing the excessive material into the recess e. The die load is also reduced by dividing the die into a plurality of segments at the location of the recess, and further dividing the second step into two steps.

Third Embodiment

[0054] The aforesaid problem of the third step in the prior art, that is, the back surface of the rack shaft cannot be formed into a true circle, is resolved by using a mandrel as shown in Figs.20a to 22c. Figs.20a, 21a and 22a are front elevation sectional views; Figs.20b, 21b and 22b are sectional views taken along line B-B in each of the front elevation sectional views; and Figs.20c, 21c and 22c are sectional views taken along line C-C in each of the front elevation sectional views. The same reference symbols in Figs.7a to 9c are used in these figures except for the symbol 112 of the mandrel.

[0055] The workpiece W formed with rack teeth upon completion of the second step is placed on the lower die set 320. At this time, as shown in Figs.20a to 20c, the workpiece W is placed such that the two legs 6 are facing up. The upper surface of the central lower die 323 is complementary to the rack tooth shape, and each of the rack teeth is fitted to this complementary rack tooth surface. The upper surface of each of the right lower die 321 and the left lower die 322 has a circular shape to which the lower surface of the workpiece W is well fitted.

[0056] A mandrel set 112 is inserted between the two legs 6. The mandrel set 112 comprises two members or segments intended to be pulled out after they are butted to each other. One of them comprises a central D-shaped portion 112b and a circular portion 112a extending from the former, and the other comprises only a circular portion. Since any composition is acceptable if the mandrel set 112 can be pulled out after operation, it is also possible that it can be divided into three members including two circular portions and one D-shaped portion, or it can be divided into two symmetrical segments at the central part of the D-shaped portion.

[0057] Then, as the upper die 310 descends, both legs 6 of the workpiece W are guided along the semi-circular concave surface, receiving a bending force directed inwardly, to start their deformation. At this time, a high bending moment is applied to a location near the roots of the legs 6 at the beginning and a small bending moment is merely applied to the location near the extremities of the legs 6. However, since the mandrel set 112 exists,

the part where the largest bending moment is applied moves along the cylindrical outer surface gradually from the roots of the legs 6 toward the extremities of the legs 6. A middle state is shown in Figs.21a to 21c and the final state is shown in Figs.22a to 22c. In this way, the back surface of the rack shaft is formed into a circular shape.

[0058] After this operation, when the upper die 310 ascends, a slight clearance is formed between the mandrel set 112 and the workpiece W by an unavoidable spring-back of the workpiece W, resulting in the mandrel set 112 being easy to pull out. After this operation, since the slightly opened butted portions can be closed by quite a low force, they are welded in a closed state by laser welding, for example. Even if this rack shaft is finished and ground, a mere slight grinding margin is required and the strength of the rack shaft is not substantially reduced by the grinding operation.

[0059] Although only preferred embodiments are specifically illustrated and described herein, it will be appreciated that many modifications and variations of the present invention are possible in light of the above teachings and within the purview of the appended claims without departing from the spirit and intended scope of the invention.